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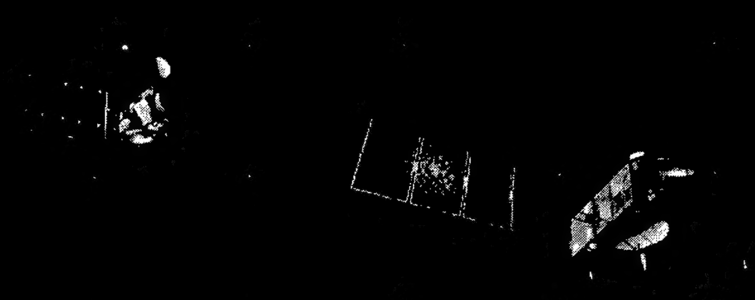

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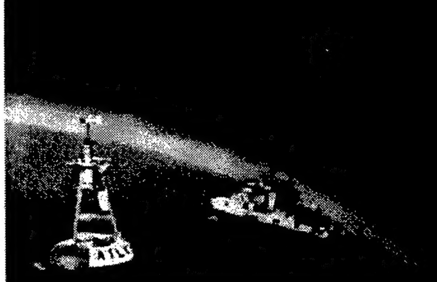

Operational Global Ocean Prediction Systems

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Abstract - Several first generation global and basin-scale ocean prediction systems are already running in real time in operational, semi-operational or pre-operational mode. They provide ocean forecasts ranging from 2 to 30 days. Most assimilate sea surface temperature, satellite altimeter and temperature profile data. Horizontal resolution ranges from 1° to 1/16° and 7 to 40 layers or levels in the vertical. Nowcast/forecast skill has been demonstrated for mesoscale variability and sea surface temperature. A wide variety of applications has been reported. Boundary conditions for real-time regional and coastal ocean prediction systems is a common one.

1. Introduction

Adequate real-time data input, computing power, numerical ocean models and data assimilation capabilities are the critical elements required for successful eddy-resolving global ocean prediction. Only recently, all of these elements have finally reached the status where this is feasible, hence the timing of the multi-national Global Ocean Data Assimilation Experiment (GODAE). First generation global and basin-scale ocean prediction systems oriented toward nowcasting and short range forecasting (up to a month) are already operational, pre-operational or semi-operational (Table 1). Pre-operational means running in real time and destined for operational use. Semi-operational means running in real time and used for operational applications, but with no specific plans to become officially operational. Seasonal to interannual/El Niño prediction, using coupled ocean-atmosphere models, is the subject of a separate GODAE Symposium paper [1] and is not considered here. This paper illustrates issues related to the development of existing systems, capabilities they have demonstrated, and operational applications.

2. Existing global and basin-scale ocean prediction systems

In developing the first generation systems different trade-offs were made to permit execution using computing power available today. For example, NLOM has relatively high horizontal resolution and a nearly global model domain but it has low vertical resolution (7 Lagrangian layers including the mixed layer) and it excludes the Arctic and most shallow water regions. Salinity and subsurface temperatures are obtained via a post-processing step using model sea surface height (SSH), sea surface temperature (SST) and statistics of the historical hydrographic data base [2,3]. NCOM is fully global and has higher vertical resolution concentrated near the surface, but it has coarser horizontal resolution. The vertical coordinate is hybrid, σ (terrain-following) in shallow water and z-level elsewhere. Because of NLOM skill in assimilating satellite altimeter data and mapping mesoscale variability, NCOM assimilates temperature (T) profiles generated using NLOM in addition to observed profiles. This symbiotic relationship effectively makes NLOM and NCOM different components of the same system [3]. The z-coordinate FOAM North Atlantic system trades areal coverage for horizontal and vertical resolution. The near-future MAP North Pacific system (Table 2) also trades areal coverage for horizontal and vertical resolution. In addition, it uses a variable grid size: 1/4° in the Kuroshio region and 1.5° east of 160°W in longitude; 1/4° from 23°N to 45°N and 1/2° outside that latitude band [4]. JMA will adopt a nested system: a fine resolution model in the northwest Pacific nested in a global model. The DIADEM system [5] uses an ensemble Kalman filter (EnKF) to assimilate data [6], a more sophisticated and expensive technique than any other system listed in Table 1. It also focuses resolution in the northern Atlantic and Nordic Seas at the expense of relatively coarse resolution at low latitudes. Recently, in DIADEM the isopycnal model MICOM [7] was replaced by a new hybrid isopycnal (ρ)/z/σ coordinate ocean model, HYCOM [8,9]. The SWAFS North World system is used mainly to host finer resolution regional and semi-enclosed seas systems.

3. Data requirements

The GODAE Strategic Plan [10] identifies sea surface height (SSH) from satellite altimetry, sea surface temperature (SST), atmospheric forcing/scatterometry and hydrographic data/ARGO PALACE floats as the most critical GODAE data requirements and these are the data types used almost universally and exclusively by the systems listed in Table 1. Satellite altimetry is the essential available data source which allows eddy-resolving ocean models to map mesoscale variability almost globally. Dynamically, SSH is an important ocean observable because (unlike SST) it is closely related to the geostrophic component of surface currents and to subsurface thermohaline structure, including the depth of the main thermocline. SST is essential for the surface mixed layer, and it provides a depiction of many ocean features. Atmospheric forcing helps models represent ocean phenomena which respond strongly to this forcing, ageostrophically or on space and time scales poorly resolved by satellite altimetry, e.g. surface Ekman currents and the mixed layer, the coastal circulation, coastally trapped waves and ocean response to hurricanes (which are represented in present numerical weather prediction (NWP) systems).

A wide variety of in situ ocean data are essential for calibration of satellite data and evaluation of ocean models and prediction systems. Although real-time hydrographic data (ARGO/PALACE floats; PIRATA, TAO and TRITON moored arrays; and other) should enhance prediction system performance, there is no prospect on the horizon for sufficient subsurface data to constrain the evolution of mesoscale variability in a data-assimilative eddy-resolving global or basin-scale ocean model. However, the historical hydrographic data base is essential to all of the ocean predictions systems in some way, e.g. as a background state, for some boundary conditions, in ocean model design, setting of model parameters, and model evaluation and/or in downward projection of surface data. The latter is a critical issue when the available real-time data is overwhelmingly at the surface. The systems in Table 1 use a variety of techniques to project surface data downward, Cooper-Haines [11] in FOAM, the EnKF in DIADEM and the statistical inference technique of Hurlburt et al. [12] in NLOM. All of the U. S. Navy systems use the statistics of the historical temperature (T) and salinity (S) profile data base in conjunction with SSH and SST for this purpose, NLOM as a post processing step [13,14,2,3]. This approach was much less effective near the equator than in other parts of the tropical and North Pacific until some TAO data were included. With relatively deep and abundant T and S profiles, the ARGO/PALACE float array may greatly improve the statistics for this approach within a few years, especially for salinity.

4. Model resolution requirements

Determining resolution requirements is a critical issue in eddy-resolving ocean prediction system design. Growing evidence indicates that ocean models, like those used for existing ocean prediction systems, need to use grid cells for each prognostic variable that are at most about 7 km across at mid-latitudes, e.g. to obtain a realistic Gulf Stream pathway in free running mode. At 12 km resolution in the Gulf Stream region, the z-level 1/9° North Atlantic model used in FOAM robustly achieved a realistic Gulf Stream pathway between Cape Hatteras and the Grand Banks at relatively coarse resolution compared to other simulations, but a less realistic pathway east of the Grand Banks. Some simulations using ocean models of similar design have not achieved a realistic Gulf Stream pathway at resolutions finer than 1/9°. The need for ~ 7 km resolution or finer is consistent with research using an NLOM Atlantic model spanning 9-47°N [15]. The authors also found that doubling the horizontal resolution to 3.5 km gave substantial improvement but doubling again to 1.7 km gave only modest additional improvement. For the NLOM grid the 7, 3.5 and 1.7 km resolutions translate to 1/16°, 1/32° and 1/64° and for "square grid" models they translate to 1/12°, 1/25° and 1/50° equatorial resolution. Much finer resolution is needed for coastal models. So far, 1/16° is the finest resolution computationally feasible for global ocean prediction and then only when using an extremely efficient ocean model, such as NLOM.

At 3.5 km, the optimal resolution is finer than might be expected based on the size of eddies. In relation to ocean eddy size, it is similar to the resolution currently used by the leading weather forecasting models in relation to the size of atmospheric highs and lows. More specifically, NRL research has shown that fine resolution of the ocean eddy scale is required to obtain coupling between upper ocean currents and seafloor topography via turbulent flow instabilities, a mechanism which occurs without direct contact between the upper ocean currents and the topography. This coupling can strongly influence the pathways of upper ocean currents and fronts, including the Gulf Stream in the Atlantic and the Kuroshio in the Pacific [16,17]. The high resolution is also required to obtain sharp fronts that span major ocean basins [16] and for adequate representation of straits and islands and their effects on currents [18]. It can even affect the model-simulated large-scale shape of ocean gyres such as the Sargasso Sea in the Atlantic [15].

Resolution requirements for data-assimilative ocean models are consistent with those for free running models [19]. A feasibility demonstration of ocean model eddy-resolving nowcast/forecast skill was performed using satellite altimeter data from TOPEX/Poseidon (T/P) and ERS-2. A 1/16° NLOM Pacific Ocean model north of 20°S and a 1/4° NLOM global ocean model were used to assimilate the data and then perform month-long forecasts initialized from the data assimilative states. The 1/16° model demonstrated (1) that satellite altimetry is an effective observing system for mesoscale ocean features, (2) that the ocean model was a skillful dynamical interpolator of satellite altimeter data in depicting mesoscale oceanic variability and (3) that the ocean model could provide skillful forecasts of mesoscale variability for a month or more, when model assimilation of the altimeter data is used to define the initial state. At mid-latitudes the 1/4° model did not demonstrate the dynamical interpolation skill nor the forecast skill shown by the 1/16° model. In the 1/4° model better nowcast results were obtained at mid-latitudes when independent analyses of SSH were assimilated, but forecast skill was still limited. In free running mode 1/8° (1/6° equatorial or 15-16 km mid-latitude resolution) global NCOM did not realistically simulate features like the Gulf Stream and the Kuroshio, hence the assimilation of SSH from NLOM via synthetic T profiles. Using simulated data from the 1/16° Pacific model, even one altimeter gave large error reduction in mapping the mesoscale when the 1/16° model was used to assimilate the data, but error was substantially reduced when simulated data from two or better three nadir beam altimeters were assimilated, results consistent with those reported by the High-resolution Ocean Topography Science Working Group [20] using a variety of sources.

5. Nowcasting and forecasting of mesoscale variability

In comparison to tide gauge time series, SSH analysis products, such as NAVO's daily MODAS2D analyses, perform relatively well in the ocean interior, particularly when the time series are filtered to remove time scales not well resolved by satellite altimetry. However, they tend to perform very poorly in regions where boundary currents and off-shelf Kelvin waves are important. Generally, they do not extend into shallow water because of multiple difficulties. Data-assimilative ocean models have a large advantage in mapping SSH in these regions because (1) they are sensitive to geometric constraints, (2) they can distinguish between boundary layer/wave guide and interior dynamics and (3) they can use atmospheric forcing to provide value added where the ocean has a relatively deterministic response, particularly on time and space scales not well resolved by altimeter data. Examples include Kelvin waves, upwelling and shallow water variability. Models also tend to represent boundary currents and their ocean interior extensions in a more coherent fashion.

Figure 1b illustrates the value of using an ocean model to assimilate altimeter data in a western boundary current region. It shows a comparison of SSH time series at Mera, Japan between tide gauge data, operational NLOM (Table 1) and the operational MODAS2D SSH analyses. Matching this tide gauge is especially challenging because it is located at the southeast corner of Japan near the Kuroshio separation from the coast (Fig. 1a). This tide gauge time series is not a deterministic response to atmospheric forcing as demonstrated by minimal correlation between SSH time series from interannual identical twin, eddy-resolving simulations which differed only in initial state details several years earlier, and by minimal correlation between either free-running model simulation and the tide gauge time series. Thus, the .96 correlation and 3.2 cm rms difference between operational NLOM and the Mera tide gauge data are due entirely to assimilation of altimeter data by an ocean model. The SSH analysis product gave a correlation of only .34 and an rms difference of 11.0 cm. The concatenated correlation between operational NLOM and 39 tide gauge time series around the world (28 island, 11 coastal) is .75 and the concatenated rms difference is 5.5 cm. For the MODAS2D SSH analyses the concatenated correlation and rms difference are .65 and 6.5 cm. Unlike Mera, some of the coastal stations are in harbors a degree or more from the NLOM time series taken at the shelf edge. All the statistics with tide gauge data used 30-day running means between 1 Dec 2000 – 31 Mar 2002 and the mean over the same time period was removed from the time series at each location.

Figure 1a shows a comparison for 18 Feb 2002 between SSH from NLOM and the pathway of the Kuroshio Extension north wall analyzed independently by NAVO from satellite IR imagery (white line). Note the close agreement between the NLOM and IR pathways east of 156°E where there was recent clear IR imagery and markedly poorer agreement west of 156°E where recent clear IR imagery was not available except for a short segment between 142° and 146°E, based on comparisons with earlier analyses. This illustrates the detail achieved in mapping mesoscale variability when using an eddy-resolving numerical ocean model to assimilate altimeter data from three satellites, T/P, GFO and ERS-2.

Figure 1c shows 30-day forecast skill for the Kuroshio region (Fig. 1a) in relation to persistence, a forecast of no change. It also shows that forecast skill is about the same in the Kuroshio region whether atmospheric

forcing is analysis quality (green line) or from an atmospheric forecast for 4 days followed by a transition to climatological forcing thereafter (red line) [21]. Many aspects of the ocean, including the Kuroshio Extension pathway, can be predicted for longer than forecast atmospheric forcing is available. On time scales of a month or more many aspects of ocean evolution are more dependent on ocean internal dynamics than on the atmospheric forcing. Since many aspects of the ocean circulation evolve much more slowly than the atmosphere (~10x slower for mesoscale variability than atmospheric weather systems), they are predictable for much longer. There are exceptions such as shallow coastal regions and sea surface temperature which can evolve rapidly and respond rapidly to the atmosphere.

6. Nowcasting and forecasting of SST and subsurface structure

Historically, simulation of SST and mixed layer depth in free running ocean models has been a severe problem because of (1) insufficient accuracy in the atmospheric forcing, (2) the use of monthly forcing when mixed layer depth and thus SST are strongly influenced by the wind events, (3) excessive vertical and horizontal diffusion in ocean models and (4) insufficient vertical resolution near the surface. Hence, in the past ocean model simulations have often relaxed to an SST climatology rather than use atmospheric thermal forcing. Solving such problems is essential to success in SST forecasting and for ocean models to provide value added in high-resolution SST analysis/nowcasting. Fortunately, major progress has been made. Now there are multiple operational and reanalysis atmospheric forcing products with sub-daily output which are sufficiently accurate for free running ocean models and SST prediction, particularly when used in conjunction with accurate latent and sensible heat flux formulations which include ocean model SST. In addition, ocean models have improved vertical and horizontal resolution and some are using mixed layer models which are less sensitive to vertical resolution, such as KPP [22] and bulk mixed layer models, which have worked quite well in isopycnal/layered ocean models with low vertical resolution. A free-running 1/8° global NLOM simulation was forced 1979-2001 by 6 hourly ECMWF reanalysis/operational 10 m winds and thermal forcing and no relaxation to observed SST. For SST it gave a median rms difference of .86°C and a median correlation of .89, when compared to 442 year-long daily time series from moored buoys over the time frame 1980-2001 [23]. These buoys were located in the equatorial and North Pacific up to 57°N, the equatorial and North Atlantic up to 38°N and the Gulf of Mexico. The flux formulation of Kara et al. [24] was used in calculating momentum fluxes from the ECMWF 10 m winds, and latent and sensible heat fluxes from ECMWF fields and ocean model SST.

High resolution mapping of SST is the subject of a separate GODAE Symposium paper [25]. Here we consider this only from an ocean model nowcasting and forecasting point of view, including the adequacy of available real-time SST data for this purpose. SSTs from operational 1/16° global NLOM were compared with unassimilated data, namely daily time series from 84 moored buoys over the time frame 8 Nov 2000 – 6 May 2002. The data are from the National Data Buoy Center, the PIRATA array in the tropical Atlantic and the TAO/TRITON array in the equatorial Pacific. The median rms difference between these time series is .36°C, and the median correlation is .93. NLOM assimilates operational 1/8° MODAS2D SST analyses produced daily by NAVO using only satellite IR MCSSTS. Since it assimilates them with a 3-hour e-folding relaxation time scale, these statistics are essentially those of the SST analyses. The model only adds some fluidic character to the SST fields in strong flow regimes and strong upwelling regions, and NLOM SST can depart substantially from the SST analyses in cloud covered regions beneath hurricanes [26]. Although the SST statistics from the NLOM system are surprisingly good, there is ample room for improvement. If an eddy-resolving ocean model with a better assimilation scheme (and preferably with higher vertical resolution and a better mixed layer model) can assimilate SST data using model SST as the first guess and provide accuracy comparable to high-resolution SST analyses, then the model has the potential to provide substantial additional value in real-time high-resolution SST mapping, e.g. (1) by increasing their fluidic character (which is excellent in clear IR imagery but tends to be lacking in existing high-resolution SST analysis products), (2) by improving accuracy in persistently cloud covered areas, (3) by improving alignment of SST and SSH fronts, and (4) by improving accuracy for mixed layer depth.

To achieve this goal, models must also achieve another goal, namely SST forecasts that are better than persistence. This has generally been demonstrated by both the 1° global and 1/3° Atlantic/Arctic British FOAM systems for the 5 or 6-day length of the forecasts. In the Northeast Atlantic region of particular British interest, the 1° global system showed forecast SST error growth only half that of persistence. The 1/3° Atlantic/Arctic system generally shows lower SST forecast error than the 1° global system, and it showed improvement in SST forecasts after the model began assimilating SSH from satellite altimetry (which improves the accuracy of the nowcast/forecast ocean circulation).

After 4 days, the 30-day 1/16° global NLOM forecasts transition from forecast toward climatological atmospheric forcing, a problem for SST forecasting. Thus, the NLOM SST forecasts relax toward climatologically corrected persistence of the initial SST with an e-folding time scale of _ the elapsed forecast length (e.g. 1-day for a 4-day and 1 week for a 4-week forecast). As a result, the SST forecast error is generally close to persistence early in the forecast and better than persistence (or climatology) later in the forecast, due to the climatological correction. The model value added is SST and SSH fronts that are better aligned than with persistence or climatology and forecast SST which is much more fluidic looking than the analysis-dominated initial state.

Surface salinity data is much more scarce than SST data, and salinity forcing (evaporation-precipitation (E-P)) is less known than the thermal forcing. However, with the launch of satellite missions like the Tropical Rainfall Measuring Mission (TRMM) (http://trmm.gsfc.nasa.gov/) which measures rainfall, and improved precipitation in atmospheric models, progress has been made. The 1° global FOAM system showed dramatic shallowing of the mixed layer (100 to 20 m) after the passage of a rainband, a result due to buoyancy input by the rain. This event was verified by salinity profiles from an ARGO/PALACE float taken before and after the event. They showed a shallow fresh layer after the event, but none before [27].

Vertical temperature profiles from both the 1° global FOAM system and the 1/16° global NLOM system have been compared with climatology and numerous unassimilated observed profiles over the global ocean. The 1° global FOAM system, which had assimilated other temperature profiles, but not satellite altimeter data, showed improvement over the Levitus climatology [28] in most regions of the world ocean, 0.1°C overall in the upper 300 m [29]. The 1/16° global NLOM system which assimilated altimeter data, but not temperature profile data, showed similar results in comparison to the MODAS climatology [2] when model SSH and SST and the statistics of the historical hydrographic data base were used to generate vertical temperature profiles. In addition, it showed the ability to map observed subsurface mesoscale features and a much larger improvement over climatology where the SSH anomaly was larger than 7 cm, ~0.5°C over the upper 300 m [3].

Sections 5 and 6 have illustrated some of the salient capabilities of existing ocean prediction systems listed in Table 1 and the present status of those capabilities. Obviously, there are many more with varying levels of success and difficulty from both a system capability and a system evaluation point of view.

7. Applications and user response

The British FOAM systems and the U.S. Navy systems in Table 1 are primarily aimed at Naval applications, many of which have dual use for civilian application. Some of these include assimilation and synthesis of global satellite data, optimum track ship routing, search and rescue, anti-submarine warfare and surveillance, tactical planning, boundary conditions for regional and coastal models, pollution and tracer tracking, and inputs to water quality assessment. The primary customer for the DIADEM system (Table 1) is the offshore oil and gas industry, which is expanding beyond shallow water into deep water, where knowledge of extreme current events is critical information. Oil spill trajectory prediction is another important need. Like most of the other systems, providing boundary conditions for regional and coastal/ecosystem models is a major application of DIADEM.

User interest in real time ocean products is illustrated by the 2,783,640 hits on the NRL Oceanography Division web pages during Jan-Apr 2002, an average of 23,197 per day from a large number of nations around the world. The vast majority of these are for real-time ocean products such as the NLOM and NCOM ocean prediction systems (Table 1), the 1/8° MODAS2D SSH and SST analyses (daily operational products from NAVO) and information about real-time altimeter data. User reported applications of ocean products include inputs to fishing and current forecasts for many regions of the world ocean by fishing service companies, location of blue whales in relation to cold eddies and ocean fronts in the northwest Pacific, studies of the swordfish fishery north of Hawaii, study of whales in the Antarctic region, study of cyanobacteria blooms in relation to ocean eddies near New Caledonia, increased scientific knowledge for exploitation and protection of marine resources, use of a hindcast in a German television program to illustrate Kelvin and Rossby waves in the tropical Pacific in relation to the '97-'98 El Niño, oil company use of nowcast/forecast ocean currents and features that could affect deep oil rigs in the Gulf of Mexico and off the coast of Brazil, monitoring of ocean features and currents near Hawaii during the raising of the Japanese fishing boat Ehime Maru by the U.S. Navy, monitoring the confluence of the Benguela Current and the South Atlantic Current in relation to tropical convection across the equatorial Atlantic, ocean research, cruise guidance for ocean research field programs, use of currents in routing sailboats and yachts, and use in scheduling geophysical hazard surveys in the Gulf of Mexico because the Loop Current can seriously affect data quality.

8. Future global and basin-scale ocean prediction systems

Table 2 is a list of global and basin-scale ocean prediction systems planned in the future based on the draft GODAE Implementation Plan and personal communications. Pre-operational systems listed in Table 1 are not included in Table 2. Most of the systems will be used primarily for ocean applications and boundary conditions for finer resolution regional and coastal ocean models. However, at FNMOC the primary purpose is a global coupled atmosphere-ocean model for improved weather forecasting and boundary conditions for regional coupled atmosphere-ocean forecast models.

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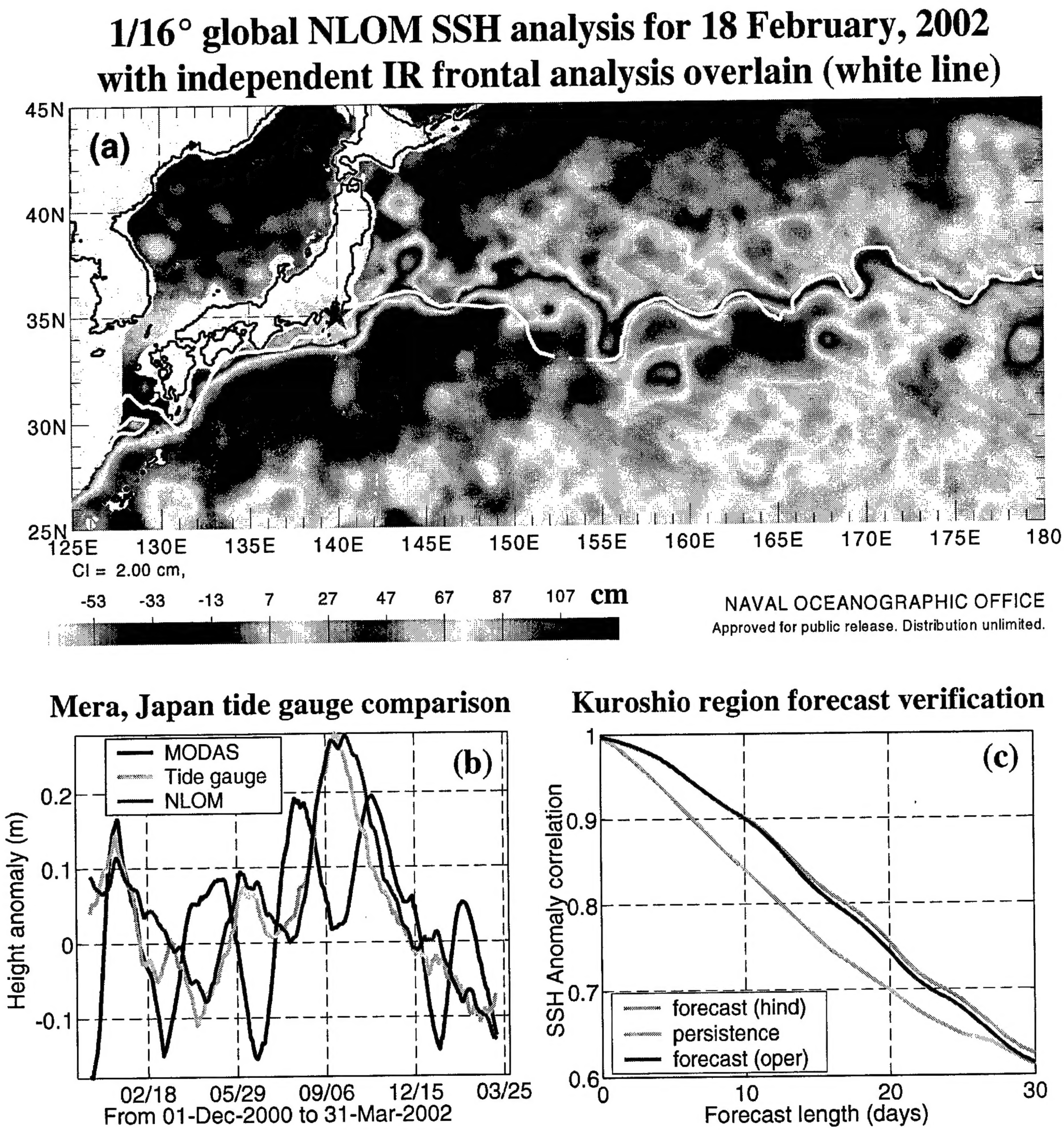

Fig. 1: (a) Sea surface height (SSH) analysis for 18 Feb. 2002 from the operational 1/16° global NLOM system (Table 1) with an independent IR frontal analysis by NAVO overlain (white line). Recent clear IR imagery for the frontal analysis was available only 142°-146°E and east of 156°E, the regions of close agreement with NLOM. The star marks the location of the Mera, Japan tide guage. (b) comparisons of SSH vs time off Mera, Japan: NLOM and MODAS2D vs tide guage data, all with a 30-day running mean. MODAS2D is a 1/8° NAVO operational, model – independent analysis of SSH from altimeter data. Both NLOM and MODAS used altimeter data from TOPEX/Poseidon, GFO and ERS-2. (c) 30-day forecast verification statistics (anomaly correlation) vs time for the Kuroshio region shown in (a) [21]. The results are means for 8 forecast periods early in 2001. Operational forecast verification (red) is compared with persistence (forecast of no change in blue) and hindcast verification (green). The hindcasts (after-the-fact forecasts) used analysis quality atmospheric forcing to show ocean forecast sensitivity to the quality of the atmospheric forcing.

TABLE 1 : Existing Real-time Global and Basin-scale Ocean Prediction Systems as of May 2002

Year Started	Coverage	Run by	System Name	Resolution horiz/vert [1]	Vertical Coordinate	Data Inputs	Assimilation technique	Forecast length (days)
Operational								
1997	Global	MetO	FOAM	1°/20	z	T profiles, IR/in situ SST	Analysis correction	5
Website: http://www.metoffice.com/research/ocean/operational/dpds/dpds_foam.html								
2001	Near global	NAVO	NLOM	1/16° / 7	Lagrangian layers	altimeter, IR SST	OI of deviations from model first guess/downward statistical inference	30
Website: http://www7320.nrlssc.navy.mil/global_nlom								
2001	Atlantic/Arctic	MetO	FOAM	1/3° / 20	z	altimeter, IR/in situ SST, T profiles, ice concentration	Analysis correction / modified Cooper-Haines	5
Semi-operational								
1998	North World	NAVO	SWAFS	[2] .27°_.21° / 23	σ	SST,T/S profiles, synthetic T/S profiles from altimetry (MODAS)	Univariate OI analysis relaxed into model	2
2001	Atlantic/Arctic	NERSC	DIADEM	[3] highly variable	ρ/z/σ	altimeter, SST, T & S profiles, ice concentration	EnKF	7
Website: http://www.theyr.is/diadem/rtweb/rtres.html								
2001	Indian Ocean & Arabian Sea	MetO	FOAM	1/3° / 20 & 1/9° / 20	z	altimeter, IR/in situ SST, T profiles	Analysis correction / modified Cooper-Haines	5
Pre-operational								
2001	Global	NRL	NCOM	[4] 1/8° / 40	σ/z	altimeter, IR SST, T profiles	OI of obs T with synthetic 3-D T from SST and NLOM SSH as first guess	5
Website: http://www7320.nrlssc.navy.mil/global_ncom								
2002	North Atlantic	MetO	FOAM	1/9° / 20	z	altimeter, IR/in situ SST, T profiles, ice concentration	Analysis correction / modified Cooper-Haines	3
Website: http://www.nerc-essc.ac.uk/las								

Notes:
Real-time research demonstrations are not included
MetO = Met Office, UK
NAVO = U.S. Naval Oceanographic Office
NERSC = Nansen Environmental and Remote Sensing Center, Norway
NRL = U.S. Naval Research Laboratory
Global NCOM is targeted for operational use in 2003 and the 1/9° North Atlantic FOAM system in 2004 with an increase to 40 levels.

EnKF = Ensemble Kalman filter
[1] Number of levels or layers
[2] Long. x Lat.
[3] with high resolution focused on the northern Atlantic/Nordic Seas, 25-30 km in the Gulf Stream Extension
[4] Global NCOM uses a "square grid" with 1/6° equatorial resolution (1/8° latitudinal @ 45°N/S)

TABLE 2: Plans for Real-time Global and Basin-scale Ocean Prediction Systems

Target year	Coverage	Run by	System or model name	Resolution horiz/vert	Vertical Coordinate	Assimilation technique
Australia						
2003	Global	BOM	ACOM	1/3° / 30	z	Statistical interpolation
France						
2003	Global	MERCATOR	OPA	1/4° / 43	z	MVOI/SOFA
2003	North Atlantic + Mediterranean Sea	MERCATOR	OPA	1/15° / 43	z	MVOI/SOFA
Japan						
2002 - 2003	Pacific, 12°-55°N	JMA	MAP	1/4-1/2° (lat) 1/4-1.5° (lon) / 21	z	Multivariate scale-dependent 4DOI relaxed into model retrospectively
Norway						
2003	Atlantic/Arctic	NERSC	DIADEM	13-50 km / 22	ρ/z/σ	EnKF
UK						
* 2003 & 2004	Global	MetO	FOAM	1/3° / 20 → 1/3° / 40	z	Analysis correction / modified Cooper-Haines for downward projection
US						
2003	Global	FNMOC	POP	1/4° / 36	z	MVOI
2003	Near global	NAVO	NLOM	1/32° / 7	Lagrangian layers	OI of deviations from model first guess / downward statistical inference
2006	Global	NAVO	HYCOM	1/12° / 26	ρ/z/σ	TBD
2007	Global	FNMOC	POP?	1/10° / TBD	z	Multivariate 3DVAR or 4DVAR
2010	Global	NAVO	HYCOM	1/25° / 26	ρ/z/σ	TBD

Notes:
Pre-operational systems listed in Table 1 are not included here.
See also notes for Table 1
BOM = Bureau of Meteorology
JMA = Japan Meteorological Agency
FNMOC = Fleet Numerical Meteorology and Oceanography Center
TBD = to be determined
* Real-time pre-operational in 2003, operational in late 2004 or early 2005 with an increase from 20 to 40 levels in the vertical.